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⑤④ **Method of producing aluminum base sintered body containing graphite.**

⑤⑦ In producing a sintered body comprising aluminum as its principal material and graphite as a lubricating additive through the steps of preparing a powder mixture of raw materials, compacting the powder mixture into a desired shape and sintering the compacted powder mixture, use is made of a graphite powder of which particles are coated with copper as the source of the entire quantity of graphite. Copper present on the surfaces of the graphite particles prevents graphite from adhering to aluminum particles and obstructing good sintering. At the stage of sintering, an eutectic reaction takes place between Cu and Al in the compacted powder mixture to form a liquid phase at a temperature below the melting point of Al. Accordingly this method gives an accurately shaped sintered body with high physical strength. The powder mixture may additionally contain a limited amount of copper powder. To enhance abrasion resistance of the sintered body, preferably the powder mixture is made to contain an adequate amount of Si preferably together with a small amount of Mg.

METHOD OF PRODUCING ALUMINUM BASE  
SINTERED BODY CONTAINING GRAPHITE

BACKGROUND OF THE INVENTION

5 This invention relates to a method of producing  
a sintered body which comprises aluminum as its principal  
material and graphite as a lubricating or antifrictional  
additive.

10 Aluminum is in wide use as a lightweight structural  
material, and recently there is an increasing trend  
to the use of aluminum alloys or aluminum base composite  
materials even for metal parts that make sliding contact  
with other metal parts during practical working. Usually  
silicon is added to aluminum to enhance abrasion resistance  
15 of the products and graphite is used as an additive  
to afford a lubricating or antifrictional property  
to the products. Either casting or sintering has been  
employed as the method of producing aluminum base metal  
parts containing graphite, but graphite incorporated  
20 into the raw materials offers difficulty to either  
the casting process or the sintering process.

In the case of casting, a serious problem is that  
it is difficult to achieve uniform distribution of  
graphite in the aluminum casting because of considerable  
25 differences in both specific gravity and wettability

between aluminum and graphite. Besides, when a relatively large amount of silicon is added with the intention of forming a hyper-eutectic composition which is effective for enhancement of abrasion resistance of the casting there arises an additional problem that the fluidity and castability of the molten metal become so inferior that it becomes difficult to obtain stable and uniform castings.

In comparison, a sintering process is advantageous in the possibility of achieving uniform distribution of graphite in aluminum and also in wasting less amounts of the materials. However, there is a serious problem that the particles of graphite adhere to the surfaces of aluminum particles during blending of the powdered raw materials and compacting of the powder mixture and act as a sort of sintering inhibitor at the stage of firing the compacted powder mixture, since graphite does not react with aluminum. As the result, the sintered body is unsatisfactory in its physical strength. It has been tried to solve this problem by performing the sintering at a temperature above the melting point of aluminum, e.g. at about 700°C, but the employment of such a high sintering temperature offers a different problem. That is, the existence of a large amount of liquid phase in the compact under sintering becomes

a cause of a significant change in the shape of the compact during sintering and makes it difficult to obtain an accurately shaped sintered body. If the sintering time is shortened to obviate this problem, it becomes difficult to produce a sintered body having a relatively large wall thickness or having both thick portions and far thinner portions because sintering in the thick portions tends to remain insufficient.

Also it has been tried to combine a sintering process with either an extrusion process or a forging process, but in either case insufficiency in the dimensional accuracy of the product and lowness of productivity remain as industrially serious problems.

Furthermore, aluminum base metal parts containing graphite produced by conventional casting or sintering methods are generally insufficient in their durability or service life because graphite exposed on the working surfaces of the metal parts are liable to separate from the surfaces during practical working of the metal parts.

#### SUMMARY OF THE INVENTION

It is an object of the present invention to provide an improved method of producing a sintered body which comprises aluminum as its principal material and graphite as a lubricating or antifrictional additive, which

method obviates the above described difficulty in sintering aluminum added with graphite by conventional sintering methods and gives an accurately shaped sintered body with strong bonding of graphite to the aluminum component in the sintered body and with satisfactorily high hardness and mechanical strength of the sintered body.

Essentially, the present invention has achieved the above object by introducing graphite into a powder mixture to be compacted and sintered in the form of particles of which surfaces are coated with copper.

A method according to the invention for producing a sintered body comprising aluminum as its principal material comprises the steps of preparing a powder mixture which comprises a minor amount of a graphite powder and a major amount of a metal powder comprising at least a major amount of aluminum, the surfaces of the particles of the graphite powder being coated with copper, compacting the prepared powder mixture into a desired shape, and sintering the compacted powder mixture in a nonoxidizing gas atmosphere.

The aforementioned metal powder may be a practically pure aluminum powder, an aluminum alloy powder or a mixture of an aluminum powder and an aluminum alloy powder.

As the effect of using a copper-coated graphite

powder, there is no possibility of the surfaces of the aluminum or aluminum alloy particles being directly covered with graphite particles during mixing of the powder materials and compacting of the powder mixture.

5 Accordingly graphite in the powder mixture does not exhibit an inhibiting effect on sintering of the compacted powder mixture, and therefore good sintering of the compacted powder mixture can be accomplished with satisfactorily high mechanical strength of the sintered

10 body. Furthermore, during the sintering process an eutectic reaction takes place between aluminum in the compacted powder mixture and copper present on the surfaces of the graphite particles to form a liquid phase at a temperature considerably lower than the  
15 melting point of aluminum. This liquid phase is quite favorable for smooth proceeding of good sintering; so that it becomes unnecessary to employ a sintering temperature higher than the melting point of aluminum.

20 In the present invention, it is preferred that the content of Cu in the copper-coated graphite powder is at least 20% by weight, and that the content of graphite in the powder mixture to be sintered is in the range from 2.0 to 10.0% by weight. It is a requisite that the entire quantity of graphite as a raw material  
25 is in the form of a copper-coated graphite powder,

but it is optional to additionally introduce a copper powder into the powder mixture. Whether a copper powder is used or not, it is preferred that the content of total copper in the powder mixture is in the range from 2.0 to 10.0% by weight.

Owing to the above described effects of copper coated on the graphite particles, the method of the invention gives a sintered body sufficiently high in hardness and mechanical strength with little changes in the shape of the compact subjected to sintering. Even when the sintered body is used as a metal part making sliding contact with another metal part, the sintered body exhibits a long service life because graphite exposed on the contacting surface of this body does not easily separate from that surface. The sintered body can be obtained with high accuracy in its dimensions even when having a relatively intricate shape, so that in some cases the sintered body in the state as sintered serves as a practical metal part without the need of any additional finishing procedure. The possibility of accomplishing sintering at a relatively low temperature is also an advantage of the method of the invention from the viewpoint of saving energy.

For example, the sintering method according to the invention is applicable to the production of bearings,

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cylinder liners, current collectors, and side plates of oil pumps.

To enhance the abrasion resistance of the sintered body, a suitable amount of silicon would be added to the powder mixture to be compacted and sintered preferably together with a small amount of magnesium. In the case of adding a relatively large amount of silicon, it is desirable to use an Al-Si alloy powder as the source of Si.

#### DESCRIPTION OF THE PREFERRED EMBODIMENTS

In the present invention, graphite is incorporated into a powder composition to be compacted and sintered for the purpose of improving the lubricating or anti-frictional property of the sintered body. Of course it is inappropriate to use an excessively large amount of graphite, it is preferred that the content of graphite in the powder composition (and naturally in the sintered body, too) falls in the range from 2.0 to 10.0% by weight of the powder composition. When the content of graphite is less than 2% the expected effect of graphite is hardly appreciable from a practical point of view. On the other hand, the existence of more than 10% of graphite causes the mechanical strength of the sintered body to considerably lower.

As an essential feature of the invention, the



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entire quantity of graphite is incorporated into the powder mixture in the form of particles individually coated with copper. A suitable Cu-coated graphite powder can be obtained by, for example, electroless copper plating of a graphite powder. It is desired that the entire surfaces of the individual particles of the graphite powder be coated with copper. To satisfy this desire, it is preferred to perform the copper coating to such extent that the content of Cu in the Cu-coated graphite powder becomes at least 20% by weight.

A primary purpose of using such a Cu-coated graphite powder is to prevent graphite particles from adhering to the surfaces of the particles of aluminum or its alloy used as the principal material for a sintered body and then acting as a sort of sintering inhibitor. However, the copper present on the surfaces of the graphite powder exhibits additional but no less important effects at the stage of sintering a compact of the powder mixture. During sintering, this copper and aluminum as the principal component of the powder mixture react with each other and diffuse into each other to form a liquid phase when the sintering temperature is above an eutectic temperature ( $548^{\circ}\text{C}$  at the eutectic point of 67%Al-33%Cu). This liquid phase is quite effective for smooth proceeding of good sintering.

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Furthermore the resultant sintered body contains aluminum-copper solid solutions which enhance the hardness and mechanical strength of the sintered body and offer the possibility of further improving the mechanical properties of the sintered body by a suitable heat treatment. Still further, copper in the sintered body serves the function of firmly retaining the graphite particles thereby greatly decreasing the possibility of separation of the graphite particles from the working surface of the sintered body in its practical use.

In view of such favorable effects of copper, it is optional to add a copper powder to the fundamental mixture of aluminum powder or aluminum alloy powder and Cu-coated graphite powder in order to desirably adjust the amount of total copper in the sintered body. However, the use of an excessively large amount of copper results in lowering of the dimensional accuracy and/or mechanical strength of the sintered body because of an unduly increased amount of liquid phase at the stage of sintering. Accordingly it is preferred that the total amount of copper in the powder mixture to be sintered is in the range from 2.0 to 10.0% by weight of the powder mixture.

A practically pure aluminum powder is of use as the aluminum component of the raw materials in a method



of the invention, but it is optional to use a suitable aluminum alloy powder in place of an aluminum powder, or jointly with an aluminum powder. Alloys of aluminum with copper, magnesium and/or silicon are particularly suitable to this use.

To enhance abrasion resistance of the sintered body, particularly during its movement under high load conditions, it is preferable to incorporate silicon into the powder mixture to be sintered. The effect of silicon on the abrasion resistance is practically appreciable when the powder mixture contains at least 0.5% by weight of Si and augments as the content of Si increases. However, there is a tendency that the tensile strength of the sintered body lowers as the Si content increases, and therefore it is inappropriate to increase the content of Si in the powder mixture beyond 25% by weight. It is favorable to a method of the invention that Al-Cu-Si ternary system has an eutectic temperature of 524°C. When the powder mixture is made to contain only less than 5% by weight of Si, it is possible and rather convenient to use a practically pure silicon powder as the source of Si. However, when the Si content is set at a value in the range from 5% to 25% by weight, it is preferred to use an aluminum-silicon alloy powder as the source of Si because

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this is quite effective for preventing significant lowering of the tensile strength of the sintered body with increase in the Si content. In this case it is preferred that the content of Si in the Al-Si alloy is in the range from 15.0 to 30.0% by weight, that is, to use a 85/15 to 70/30 Al-Si alloy. The use of an Al-Si alloy containing less than 15% of Si is inefficient for enhancing the abrasion resistance of the product, but the use of an Al-Si alloy containing more than 30% of Si makes it difficult to obtain an accurately shaped and densely sintered body by compacting and sintering the powder mixture.

It is preferred to add a small amount of a magnesium powder to the powder mixture to be sintered, particularly when the powder mixture contains silicon. A first reason is that, during sintering of the compacted powder mixture, magnesium and aluminum react with each other and diffuse into each other to form a liquid phase at temperatures above a relatively low eutectic temperature, the liquid phase being effective for smooth proceeding of good sintering. Secondly, during sintering magnesium reacts with silicon added for the above described purpose to precipitate  $Mg_2Si$  which is helpful for age hardening of the sintered body. These effects of magnesium are practically appreciable with little adverse effects

when the content of Mg in the powder mixture is in the range from 0.2 to 2.0% by weight. The existence of more than 2.0% of Mg is undesirable for the same reason as the undesirableness of the existence of an excessively large amount of Cu.

Blending of the above described raw materials in the form of dry powders can be accomplished by a known method and apparatus. To facilitate the succeeding compacting operation, a very small amount of an organic solid or plastic lubricating agent may be added to the mixture of the above described powders.

After thorough blending, the powder mixture is compacted into a coherent mass of a desired shape by using a metal die set and a suitable pressing machine. The compacting operation is usually carried out at room temperature. Where the powder mixture contains a lubricating agent, it is recommended to adequately heat the compact in advance of its sintering in order to completely decompose the lubricating agent to gaseous substances and dissipate them.

Sintering of the compacted powder mixture is accomplished by sufficiently heating the compact in a dry and nonoxidizing gas atmosphere. In the present invention, the sintering temperature can be made below the melting point of Al, 660°C. In most cases, a suitable sintering

temperature is in the range from about 530°C to about 620°C.

Optionally, the sintered body may be subjected to an aging heat treatment or an age hardening treatment. If necessary, the sintered body may be subjected to additional cold or hot compression. Depending on the intended use of the sintered body, the micropores in the sintered body may be impregnated with oil.

The invention will be further illustrated by the following nonlimitative examples.

#### EXAMPLE 1

Use was made of a graphite powder of which particle size was adjusted such that all the particles passed through 100-mesh sieve (0.147 mm openings) but retained on 325-mesh sieve (0.043 mm openings). The same graphite powder was used throughout the succeeding examples and comparative experiments.

The surfaces of the particles of this graphite powder were coated with copper by the following process. First the graphite powder was subjected to degreasing by immersion in an aqueous solution of potassium dichromate and sulfuric acid. After that, the graphite powder was immersed in an aqueous solution of stannous chloride and hydrochloric acid for the purpose of sensitizing the particles surfaces and then immersed in an aqueous

5 solution of palladium chloride and hydrochloric acid  
to activate the particles surfaces. The activated  
graphite powder was immersed in a conventional electroless  
copper-plating solution to deposit copper on the surfaces  
of the individual particles. In this example, the  
electroless plating process was performed such that  
the weight of the deposited copper reached the weight  
of the graphite powder. That is, the copper-coated  
graphite powder contained 50% by weight of Cu. The  
10 particle size of the Cu-coated graphite powder was  
adjusted such that all the particles passed through  
100-mesh sieve but retained on 325-mesh sieve.

15 An aluminum powder used in this example (and also  
in the succeeding examples and comparative experiments)  
had a purity of at least 99.7% by weight; and all the  
particles of this aluminum powder passed through 80-mesh  
sieve (0.175 mm openings).

20 To prepare a powder mixture to be sintered, 90.0 parts  
by weight of the aluminum powder and 10.0 parts by  
weight of the Cu-coated graphite powder were blended  
in a conventional V-shaped blender for a period of  
20 min, with the addition of wax amounting to 1.0%  
by weight of the total of the blended powders as a  
lubricating agent to facilitate subsequent pressing  
25 of the powder mixture. Since the Cu-coated graphite



powder contained 50% by weight of Cu, this powder mixture consisted of 90.0% of aluminum, 5.0% of graphite and 5.0% of copper by weight, excluding the wax.

The thus prepared powder mixture was compacted in a metal die by application of a pressure of 5000 kg/cm<sup>2</sup> to form test pieces for tensile strength test by an Instron universal tester. Under the same pressing condition, differently shaped test pieces for Timken abrasion test were also formed.

Preparatory to sintering, the compacts were heated in a nitrogen gas atmosphere at 400°C for 1 hr to decompose and dissipate the wax used as lubricant. After this heat treatment the compacts were sintered in a nitrogen gas atmosphere, which had been dehumidified such that the dew point was below -40°C, for 1 hr at a sintering temperature of 560°C.

The sintered test pieces were maintained at a temperature of 505°C for 1 hr and immediately quenched in hot water maintained at 80°C, and the quenched test pieces were subjected to an aging treatment that was an 18 hr heat treatment at a constant temperature of 160°C.

The two groups of test pieces obtained through these procedures were subjected to tensile strength test by an Instron universal tension tester and abrasion



test by a Timken tester, respectively. In the abrasion test, a ring made of gray cast iron (FC 20) was radially pressed against each test piece under a load of 9 kg and continuously rotated at a peripheral velocity of 2 m/sec for a period of 50 hr, while lubricating oil (No. 50 machine oil) was applied at a rate of 0.5 ml/min. The degree of abrasion of the test piece was expressed by the width of the trace of abrasion appeared on the surface of the test piece. The results of these tests are presented in the following Table 1 together with the data in the succeeding examples.

The examples and comparative experiments described hereafter are modifications of Example 1 in respect of the composition of the powder mixture subjected to sintering. Blending of the raw materials, compacting of powder mixture, sintering of the compacts, quenching and aging of the sintered test pieces and the tensile and abrasion tests were carried out in accordance with Example 1 unless noted specifically. The amounts of the ingredients are all given by weight. The compositions of the powder mixtures sintered in the examples and comparative experiments are shown in Tables 1 and 2.

#### EXAMPLES 2 and 3

In these examples, a silicon powder having a purity of at least 98.8% by weight and a magnesium powder

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having a purity of at least 99.5% by weight were added to the powder mixture of aluminum and Cu-coated graphite. The particles of the silicon powder passed through 325-mesh sieve, and the particles of the magnesium powder passed through 200-mesh sieve (0.074 mm openings).

In Example 2, the powder mixture consisted of 10.0% of the Cu-coated graphite powder used in Example 1, 1.0% of the silicon powder, 0.5% of the magnesium powder and the balance (88.5%) of the aluminum powder. In Example 3, the amount of the silicon powder was increased to 4.0% with corresponding decrease of the aluminum powder to 85.5%. In Example 3, the sintering temperature was lowered to 550°C, and the heating of the sintered test pieces for quenching was performed at 490°C for 1 hr. (The same modifications of the temperatures were made also in other examples and experiments in cases where more than 1% of Si was contained in the powder mixture.)

#### EXAMPLE 4

A powder of an Al-Si alloy consisting of 85% of Al and 15% of Si was used in place of the silicon powder in Examples 2 and 3. The aluminum powder mentioned in Example 1 and the aforementioned silicon powder were used as the raw materials for this Al-Si alloy. The particles of this alloy powder passed through 80-mesh

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sieve.

A powder mixture prepared in this example contained 33.35% of the Al-Si alloy powder and 56.15% of the aluminum powder. Analytically, therefore, the content of Si in this mixture was 5.0% and the content of Al was 84.5% as shown in Table 1.

#### EXAMPLES 5 to 7

In place of the Al-Si alloy mentioned in Example 4, use was made of an Al-Si alloy which consisted of 80% of Al and 20% of Si and was pulverized into particles that passed through 80-mesh sieve.

The powder mixture of Example 5 contained 35.0% of the Al-Si alloy powder and 54.5% of the aluminum powder and, therefore, 7.0% of Si and 82.5% of Al when expressed analytically. In Example 6, the amount of the Al-Si alloy powder was increased to 60.0% to increase the Si content to 12.0% with corresponding decrease in the amount of the aluminum powder to 29.5% to result in a decrease of the total content of Al to 77.5%.

In Example 7, the amount of the Al-Si powder was increased to 89.5% to increase the Si content to 17.9%. In this case the aluminum powder was not used, so that the entire amount of Al (71.6%) was given by the Al-Si alloy.

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## EXAMPLE 8

An Al-Si alloy powder consisting of 70% of Al and 30% of Si was used. The particles of this alloy passed through 80-mesh sieve. The powder mixture of this example contained 83.35% of the Al-Si alloy powder and 6.15% of the aluminum powder. Analytically, therefore, this mixture contained 25.0% of Si and 64.5% of Al.

## EXAMPLES 9 and 10

These two examples were different from Example 2 only in that the amount of the Cu-coated graphite powder in the powder mixture was increased to 15.0% and 20.0%, respectively, with corresponding decreases in the amount of the aluminum powder.

## EXAMPLE 11

This example was different from Example 2 firstly in that the amount of the Cu-coated graphite powder in the powder mixture was decreased to 6.0% and secondly that a copper powder was added to the ingredients so as to occupy 2.0% of the powder mixture. The copper powder had a purity of at least 99.0% by weight, and the particles of this powder passed through 325-mesh sieve.

## EXAMPLES 12 and 13

In these two examples, a Cu-coated graphite powder analytically consisting of 40% of graphite and 60%



of copper was used in place of the Cu-coated graphite powder (50% Cu) in the foregoing examples. The particles of this Cu-coated graphite powder passed through 100-mesh sieve but retained on 325-mesh sieve. In Example 13, the content of Cu in the powder mixture was further increased by additionally using the copper powder mentioned in Example 11.

#### EXAMPLES 14 and 15

In these examples, a Cu-coated graphite powder analytically consisting of 80% of graphite and 20% of Cu was used. The particles of this Cu-coated graphite powder passed through 100-mesh sieve but retained on 325-mesh sieve. In both of these two examples, the copper powder mentioned in Example 11 was used as an additional ingredient of the powder mixture.

Table 1 Examples

|        | Composition (Wt%)                |          |         |          |      |     |      | Tensile Strength (kg/mm <sup>2</sup> ) | Abrasion (mm) |              |
|--------|----------------------------------|----------|---------|----------|------|-----|------|--|---------------|--------------|
|        | Cu-coated Graphite (graphite/Cu) | Graphite | Free Cu | Total Cu | Si   | Mg  | Al   |  |               | Source of Si |
| Ex. 1  | 10.0 (50/50)                     | 5.0      | 0       | 5.0      | 0    | 0   | 90.0 |  | 23            | 3.5          |
| Ex. 2  | 10.0 (50/50)                     | 5.0      | 0       | 5.0      | 1.0  | 0.5 | 88.5 |  | 25            | 3.3          |
| Ex. 3  | 10.0 (50/50)                     | 5.0      | 0       | 5.0      | 4.0  | 0.5 | 85.5 |  | 15            | 3.0          |
| Ex. 4  | 10.0 (50/50)                     | 5.0      | 0       | 5.0      | 5.0  | 0.5 | 84.5 | Al-Si (85-15)                          | 20            | 2.3          |
| Ex. 5  | 10.0 (50/50)                     | 5.0      | 0       | 5.0      | 7.0  | 0.5 | 82.5 | Al-Si (80-20)                          | 18            | 2.3          |
| Ex. 6  | 10.0 (50/50)                     | 5.0      | 0       | 5.0      | 12.0 | 0.5 | 77.5 | Al-Si (80-20)                          | 16            | 2.1          |
| Ex. 7  | 10.0 (50/50)                     | 5.0      | 0       | 5.0      | 17.9 | 0.5 | 71.6 | Al-Si (80-20)                          | 14            | 1.8          |
| Ex. 8  | 10.0 (50/50)                     | 5.0      | 0       | 5.0      | 25.0 | 0.5 | 64.5 | Al-Si (70-30)                          | 12            | 1.7          |
| Ex. 9  | 15.0 (50/50)                     | 7.5      | 0       | 7.5      | 1.0  | 0.5 | 83.5 |  | 16            | 3.1          |
| Ex. 10 | 20.0 (50/50)                     | 10.0     | 0       | 10.0     | 1.0  | 0.5 | 78.5 |  | 12            | 2.4          |
| Ex. 11 | 6.0 (50/50)                      | 3.0      | 2.0     | 5.0      | 1.0  | 0.5 | 90.5 |  | 28            | 3.9          |
| Ex. 12 | 12.5 (40/60)                     | 5.0      | 0       | 7.5      | 1.0  | 0.5 | 86.0 |  | 17            | 3.9          |
| Ex. 13 | 12.5 (40/60)                     | 5.0      | 2.5     | 10.0     | 1.0  | 0.5 | 83.5 |  | 14            | 4.1          |
| Ex. 14 | 6.25 (80/20)                     | 5.0      | 1.75    | 3.0      | 1.0  | 0.5 | 90.5 |  | 29            | 3.3          |
| Ex. 15 | 6.25 (80/20)                     | 5.0      | 6.75    | 8.0      | 1.0  | 0.5 | 85.5 |  | 16            | 3.8          |

## COMPARATIVE EXPERIMENTS I to III

5 In these experiments, the graphite powder mentioned in Example 1 was used in place of the Cu-coated graphite powders used in the foregoing examples. To obtain powder mixtures containing Cu, use was made of the copper powder mentioned in Example 11.

10 In Experiments I and II, the aluminum powder mentioned in Example 1 and the silicon powder mentioned in Example 2 were used. In Experiment III, the powder mixture contained 89.5% of the 80/20 Al-Si alloy powder mentioned in Examples 5-8 without containing the pure aluminum powder. In every Experiment the powder mixture contained 0.5% of the aforementioned magnesium powder.

## COMPARATIVE EXPERIMENT IV

15 Use was made of a Cu-coated graphite powder analytically consisting of 85% of graphite and 15% of Cu. The particles of this powder passed through 100-mesh sieve but retained on 325-mesh sieve. The aforementioned copper powder was used as an additional ingredient.

## COMPARATIVE EXPERIMENTS V and VI

20 In these two experiments, the powder mixture of Example 2 was modified by the addition of relatively large amounts of the aforementioned copper powder with corresponding decreases in the amounts of the aluminum powder.

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## COMPARATIVE EXPERIMENT VII

As a sole modification of Example 3, the amount of the silicon powder in the mixture was increased from 4.0% to 7.0%, with corresponding decrease in the amount of the aluminum powder.

## COMPARATIVE EXPERIMENT VIII

The powder mixture of Example 4 was modified by using an Al-Si alloy consisting of 87% of Al and 13% of Si in place of the 85/15 Al-Si alloy in Example 4. In this Experiment the powder mixture was made to contain 38.45% of the Al-Si alloy, so that the content of the aluminum powder was decreased to 51.05%.

## COMPARATIVE EXPERIMENT IX

Example 8 was modified by using an Al-Si alloy consisting of 65% of Al and 35% of Si in place of the 70/30 Al-Si alloy in Example 8. In this Experiment the powder mixture was made to contain 71.45% of the Al-Si alloy, so that the content of the aluminum powder was increased to 18.05%. The test pieces obtained by compacting and sintering this powder mixture were inferior in appearance and physical properties and unsuited to the tensile and abrasion tests.

## COMPARATIVE EXPERIMENT X

This experiment was also a modification of Example 8. In this case the amount of the 70/30 Al-Si alloy in





the powder mixture was increased to 89.5% so that the  
Si content in the powder mixture increased to 26.85%.  
The aluminum powder was not used, but analytically  
the powder mixture contained 62.65% of Al that was  
entirely provided by the Al-Si alloy.

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Table 2 Comparative Experiments

|           | Composition (Wt%)                |          |         |          |       |     |       |               | Tensile Strength (kg/mm <sup>2</sup> ) | Abrasion (mm) |
|-----------|----------------------------------|----------|---------|----------|-------|-----|-------|---------------|--|---------------|
|           | Cu-coated Graphite (graphite/Cu) | Graphite | Free Cu | Total Cu | Si    | Mg  | Al    | Source of Si  |  |               |
| Exp. I    | 0                                | 3.0      | 5.0     | 5.0      | 1.0   | 0.5 | 90.5  | Al-Si (80-20) | 7                                      | 7.8           |
| Exp. II   | 0                                | 10.0     | 5.0     | 5.0      | 1.0   | 0.5 | 83.5  |               | 3                                      | 4.2           |
| Exp. III  | 0                                | 5.0      | 5.0     | 5.0      | 17.9  | 0.5 | 71.6  |               | 4                                      | 3.8           |
| Exp. IV   | 5.88 (85/15)                     | 5.0      | 4.12    | 5.0      | 1.0   | 0.5 | 88.5  |               | 8                                      | 5.6           |
| Exp. V    | 10.0 (50/50)                     | 5.0      | 7.0     | 12.0     | 1.0   | 0.5 | 81.5  | Al-Si (87-13) | 6                                      | 6.2           |
| Exp. VI   | 10.0 (50/50)                     | 5.0      | 10.0    | 15.0     | 1.0   | 0.5 | 78.5  |               | 8                                      | 3.6           |
| Exp. VII  | 10.0 (50/50)                     | 5.0      | 0       | 5.0      | 7.0   | 0.5 | 82.5  |               | 3                                      | -             |
| Exp. VIII | 10.0 (50/50)                     | 5.0      | 0       | 5.0      | 5.0   | 0.5 | 84.5  |               | 18                                     | 5.0           |
| Exp. IX   | 10.0 (50/50)                     | 5.0      | 0       | 5.0      | 25.0  | 0.5 | 64.5  | Al-Si (65-35) | -                                      | -             |
| Exp. X    | 10.0 (50/50)                     | 5.0      | 0       | 5.0      | 26.85 | 0.5 | 62.65 | Al-Si (70-30) | 4                                      | 6.4           |

## WHAT IS CLAIMED IS:

1. A method of producing a sintered body which comprises aluminum as a principal material thereof and graphite as a lubricating additive, the method comprising the steps of:

preparing a powder mixture which comprises a minor amount of a graphite powder and a major amount of a metal powder comprising at least a major amount of aluminum, the surfaces of the particles of said graphite powder being coated with copper;

compacting said powder mixture into a desired shape; and

sintering the compacted powder mixture in a nonoxidizing gas atmosphere.

2. A method according to Claim 1, wherein the content of graphite in said powder mixture is in the range from 2.0 to 10.0% by weight of said powder mixture, the content of Cu in the copper-coated graphite powder being at least 20% by weight of the copper-coated graphite powder.

3. A method according to Claim 2, wherein the content of Cu in said powder mixture is in the range from 2.0 to 10.0% by weight.

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4. A method according to Claim 3, wherein said metal powder is an aluminum powder.

5. A method according to Claim 3, wherein said powder mixture further comprises Mg amounting to 0.2 to 2.0% by weight of said powder mixture.

6. A method according to Claim 2, wherein said powder mixture further comprises Si amounting to 0.5 to 25% by weight of said powder mixture.

7. A method according to Claim 6, wherein said powder mixture further comprises Mg amounting to 0.2 to 2.0% by weight of said powder mixture.

8. A method according to Claim 6, wherein said Si is substantially entirely in the form of a silicon powder, the content of said Si in said powder mixture being not greater than 5% by weight.

9. A method according to Claim 6, wherein said Si is substantially entirely in the form of an aluminum-silicon alloy powder, the content of said Si in said powder mixture being in the range from 5 to 25% by weight.

10. A method according to Claim 9, wherein the content of Si in said aluminum-silicon alloy powder is in the range from 15.0 to 30.0% by weight.

11. A method according to Claim 10, wherein said metal powder is a mixture of an aluminum powder and said aluminum-silicon alloy powder.

12. A method according to Claim 10, wherein said metal powder is entirely said aluminum-silicon alloy powder.

13. A method according to Claim 2, 6 or 7, wherein said powder mixture further comprises a copper powder, the total content of Cu in said powder mixture being in the range from 2.0 to 10.0% by weight of said powder mixture.

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